Oak Ridge National Laboratory

High Power and Dynamic Wireless Charging of Electric Vehicles (EVs)

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Oak Ridge National Laboratory (ORNL)

2020 U.S DOE Vehicle Technologies Office Annual Merit Review

June 04, 2020 Project ID: ELT197

Overview

Timeline

- Start Date: Oct 2019
- End Date: Sep 2021
- 50% Complete

Budget

DOE Total Share: $11,275K

FY $K	ORNL	INL	NREL
FY19	$3,075	$675	$250
FY20	$2,900	$875	$250
FY21	$2,900	$825	$250
Total	$8,875	$2,325	$750

Barriers

- **Power Density**: Developing a compact vehicle coil and power electronics assembly which can receive 200 kW power dynamically
- **Efficiency**: Achieving 90 % efficiency in a vehicle integrated dynamic wireless charging system
- **Controllability:** Identifying and implementing a control and communication system which can perform wide range power regulation without compromising efficiency or power density

Partners

National Laboratories

Oak Ridge National Laboratory: Veda Galigekere, Jason Pries, Omer Onar, Lincoln Xue, Rong Zeng, Subho Mukherjee, Gui-Jia Su, Emre Gurpinar, Shajjad Chowdhury, Randy Wiles, Jon Wilkins, Larry Seiber, Cliff White, Burak Ozpineci, and David Smith

Idaho National Laboratory: Richard Carlson and Bo Zhang

NREL: Ahmed Mohamed, Andrew Meintz, Kevin Walkowicz and Cory Sigler

External Partners

Hyundai Kia American Technical Center

American Center for Mobility

Virginia Tech Transportation Institute

Any proposed future work is subject to change based on funding levels

Project Objectives and Relevance

Relevance: Dynamic EV charging can significantly alleviate range anxiety and concurrently reduce the on-board battery requirement (weight and cost reduction)

Overall Objective: Design, develop, build, and validate vehicle integrated 200 kW dynamic wireless electric vehicle (EV) charging

- Conduct a high-level cost study → Feasibility targets for light duty (LD) vehicles
- Perform gap analysis of SOA systems → R & D required to realize a viable dynamic wireless power transfer (DWPT) solution
- Explore novel technologies and materials to enable practicable high-power DWPT:
  - Compact coils and power electronics
  - Optimal resonant network and control strategy
  - Roadway embeddable coil structure
  - Mitigation of impact on grid and vehicle body impact on power transfer

FY 2020 Objectives:

- Complete modeling, design, development, and validation of 200 kW dynamic wireless EV charging system based on DWPT
- Develop shielding techniques and data acquisition system for high power DWPT system
- Develop a system analysis tool to explore the feasibility of large-scale deployment of DWPT system (E-Roads) and explore Atlanta as a case study

Any proposed future work is subject to change based on funding levels

FY20 Milestones and Go/No-Go Decision

Milestones

Lab	Date	Milestones	Status
ORNL	6/30/2020	Complete power electronics hardware design and assembly for 200 kW operation	In progress
ORNL	9/30/2020	Validate 200 kW WPT power transfer capability	In progress
INL	3/31/2020	Develop concept design of EM-field passive shielding for safe 200kW DWPT operation	Completed
INL	9/30/2020	Complete EM-field passive shielding design for integration into ORNL's 200kW DWPT	In progress
NREL	5/30/2020	Complete development for the system analysis tool (E-Roads) with preliminary test cases	In progress
NREL	9/30/2020	Complete test cases for different designs, allocation and EV models	In progress

Go/No-Go Decision Point

Lab	Date	Go/No-Go Decision	Status
ORNL	6/30/2020	If standalone 200 kW power transfer capability is validated, proceed with evaluating dynamic power transfer capability	In progress

Any proposed future work is subject to change based on funding levels

FY21 Milestones and Go/No-Go Decision

Milestones

Lab	Date	Milestones	Status
ORNL	6/30/2021	Validate functionality of the high power dynamic wireless charging system.	Planned
ORNL	9/30/2021	Evaluate performance of dynamic wireless EV charging system based on performance	Planned
INL	3/31/2021	Complete data acquisition system required for dynamic WPT	Planned
INL	9/30/2021	Assist with the evaluate and demonstration of ORNL WPT system during static and/or dynamic operation	Planned
NREL	9/30/2021	Determine the impact of DWPT for Medium- and Heavy-Duty (MD/HD) fleets	Planned

Go/No-Go Decision Point

Lab	Date	Go/No-Go Decision	Status
ORNL	6/30/2021	If basic functionality of robust dynamic wireless EV charging is proven at low speed tests, proceed with performance evaluation	Planned

Any proposed future work is subject to change based on funding levels

Overall Approach

Goal: Validate a vehicle integrated dynamic wireless EV charging system with parameters which enable it to be economically viable in real world conditions

FY19:

Determine Technical Targets for Feasibility

- High level cost and feasibility studies
- Review of SOA systems
- Technology gap analysis
- Analytical and simulation studies

FY20:

Validate 200 kW DWPT System in Laboratory

- Power electronics and controls
- DWPT coils and resonant network
- EMI shielding
- Data acquisition

FY21:

Validate 200 kW Vehicle Integrated DWPT System in Real World

- Real-world validation
- Vehicle body interference
- Control and communication system
- Use cases

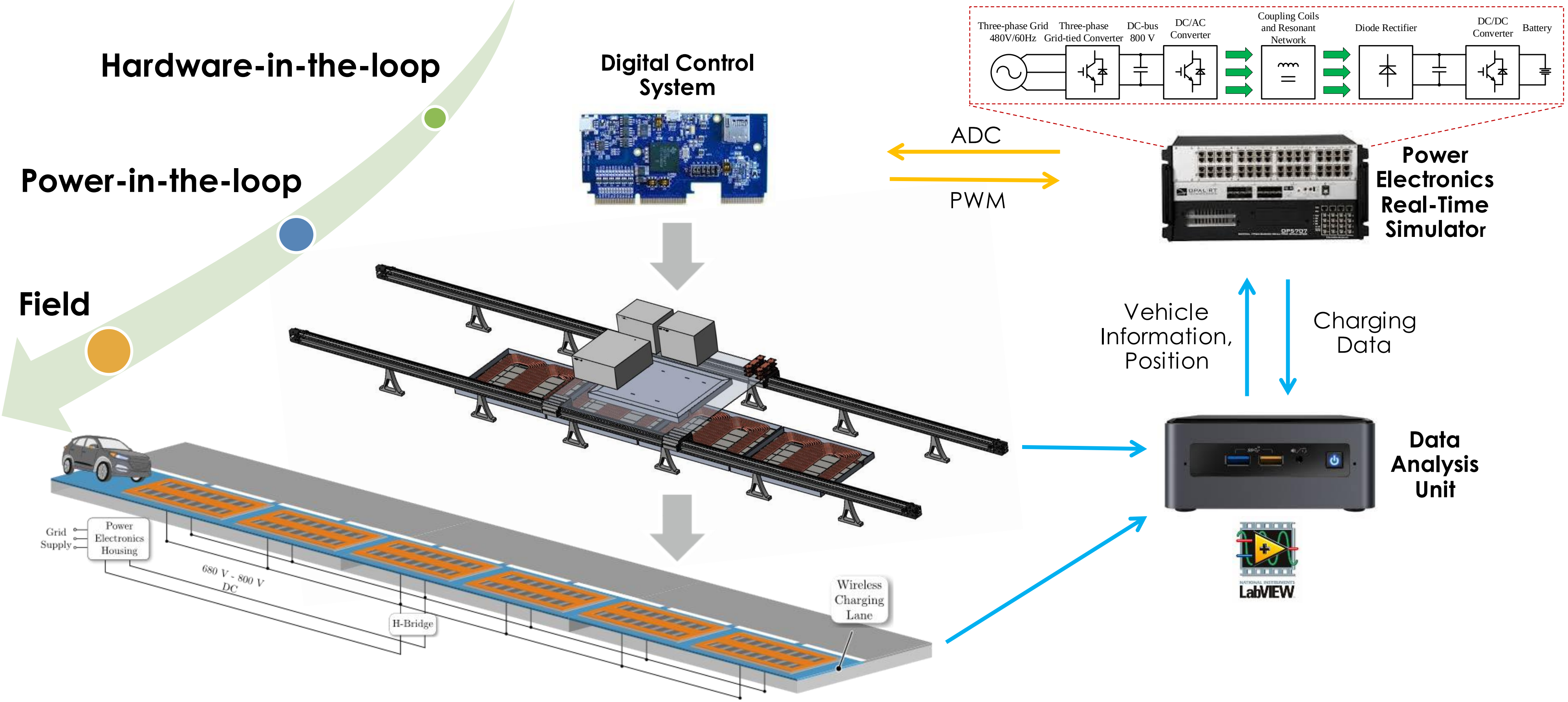
Any proposed future work is subject to change based on funding levels

Approach: Proof of Concept Validation

Goal: To develop and validate dynamic models necessary to develop optimal power control strategy to realize 200 kW dynamic charging

Challenges:

- Short power transfer window (~5 ms)
- High power transfer rate (200 kW)
- Accurate power transfer controllability and minimal oscillations



Sequence of steps for proof of concept validation

Overall Project Timeline

FY19				FY20				FY21			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
High level cost and feasibility studies											
			Go/No-Go Decision Point	Development and laboratory validation of 200 kW dynamic wireless power transfer system							
							Go/No-Go Decision Point	Demonstration of vehicle integrated high power dynamic wireless EV charging system			

FY19 Go/No-Go Decision Point: If the high-level cost study indicates feasibility, proceed with hardware design and development

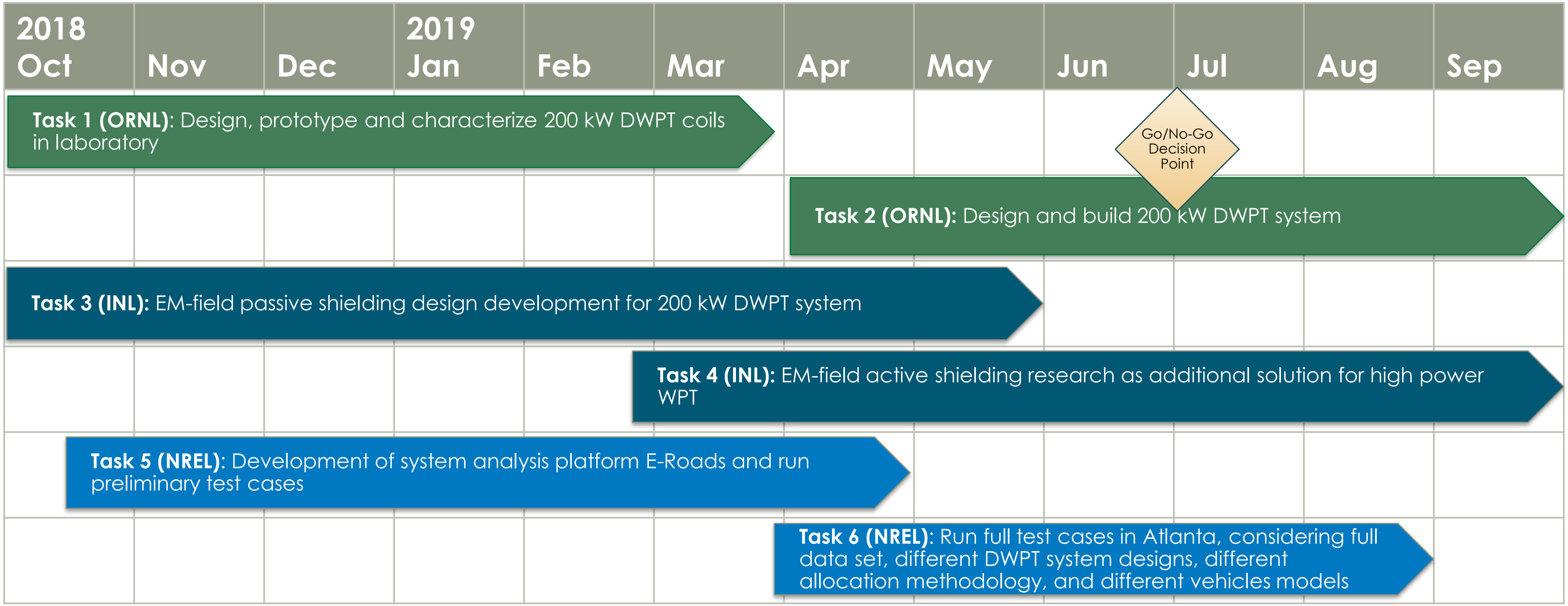
Outcome: Proceed with hardware design and development

FY20 Go/No-Go Decision Point: If standalone test of 200 kW power electronics is successful, proceed with integration of PE and WPT coils

Outcome: In progress

Any proposed future work is subject to change based on funding levels

FY20 Timeline



FY20 Go/No-Go Decision Point: If standalone test of 200 kW power electronics is successful, proceed with integration of PE and WPT coils

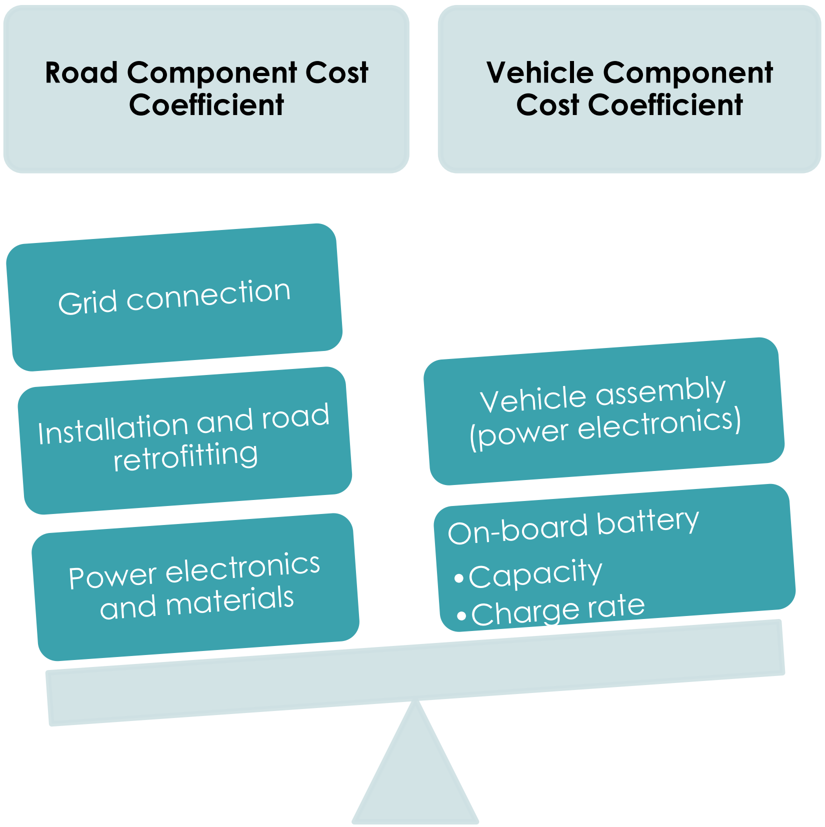
Outcome: In progress

Any proposed future work is subject to change based on funding levels

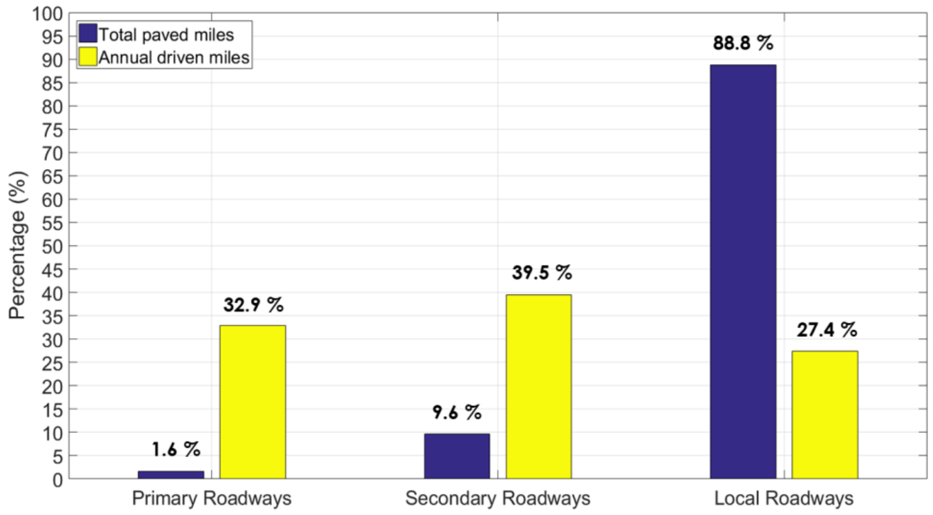
Technical Accomplishments FY19: Completed High-Level Cost and Feasibility Studies

Goal: Identify optimal power transfer level to minimize infrastructure cost without penalizing vehicle cost or performance

Developed a comprehensive cost model to achieve charge balancing solution for LD vehicles on primary roadways



Parameters included in the cost model



Total paved miles and annual driven miles by roadway type in USA [1]

Total paved roadway miles in USA – 4.2 million

1. **Primary** – Interstate and other freeways and expressways
2. **Secondary** – Other principal arterial and minor arterial roadways
3. **Local roadways –** All other roadways

Target: Charge balanced mode (unlimited range) for LD EVs
- Primary roadways
- One electrified lane
- Considerable non DWPT range

[1] Office of Highway Policy Information. (2014). Public road length- 2014: Miles by type of surface and ownership/functional system national summary.

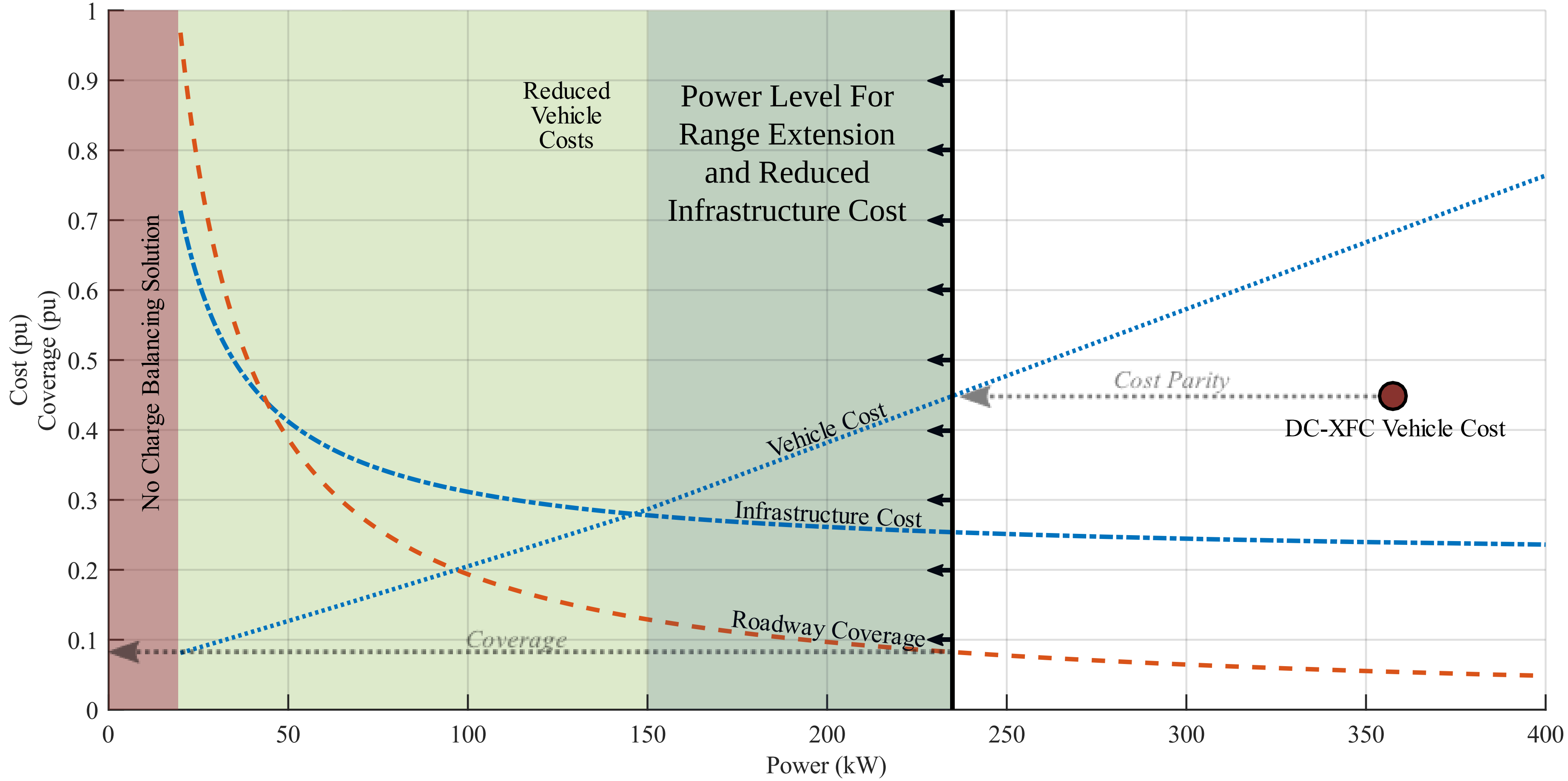
Technical Accomplishments FY19: Completed High-Level Cost and Feasibility Studies

LD Vehicle Assumptions	
Average Speed	65MPH
Minimum Battery Capacity	37kWh
DC-XFC Battery Capacity	112kWh, 4C ΔSOC=80%

Minimum Coverage DWPT Solution	
Power	**235kW**
Battery Capacity	59kWh*
C-Rate	4.0
Roadway Coverage	8.2%
Electrified Miles	5,500 Miles

*Battery charge rate limited to 4C

Power level for range extension and reduced infrastructure cost: 150 kW- 235 kW



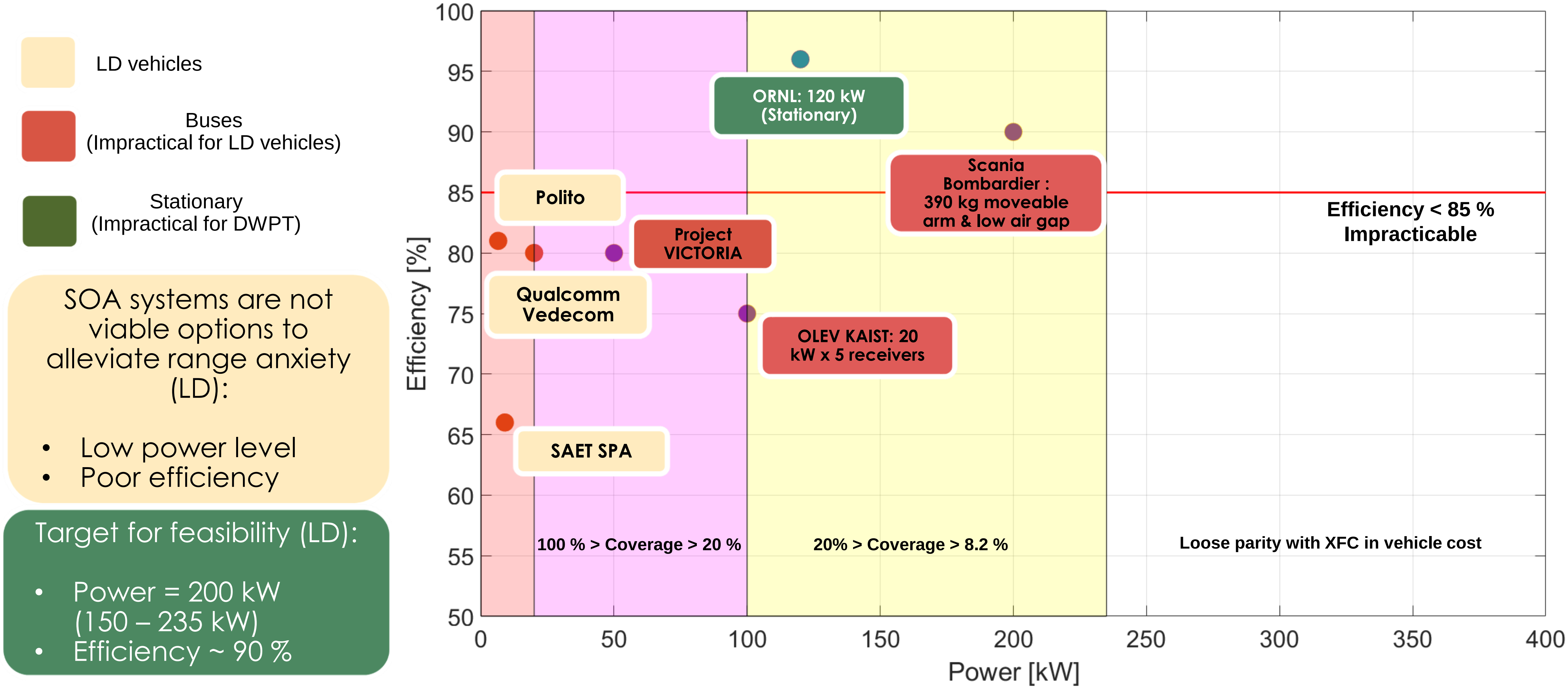
Roadway coverage and cost as a function of power transfer level for LD vehicles and primary roadways

Total paved miles – 4.2 Million

- 1.6 % of total paved miles or 67,200 miles – primary roadways
- 8.2 % of primary roadways or 5,500 miles – electrified roadway

Technical Accomplishments FY19: Completed Review of SOA Systems

Goal: Review the existing DWPT demonstrations for power transfer level and efficiency



SOA systems are not viable options to alleviate range anxiety (LD):

- Low power level
- Poor efficiency

Target for feasibility (LD):

- Power = 200 kW (150 – 235 kW)
- Efficiency ~ 90 %

Power transfer level and efficiency of state-of-the-art DWPT demonstrations

Technical Accomplishments FY19: Completed Review of SOA Systems

Goal: Review the existing DWPT demonstrations for vehicle coil power density and power level

LD vehicles

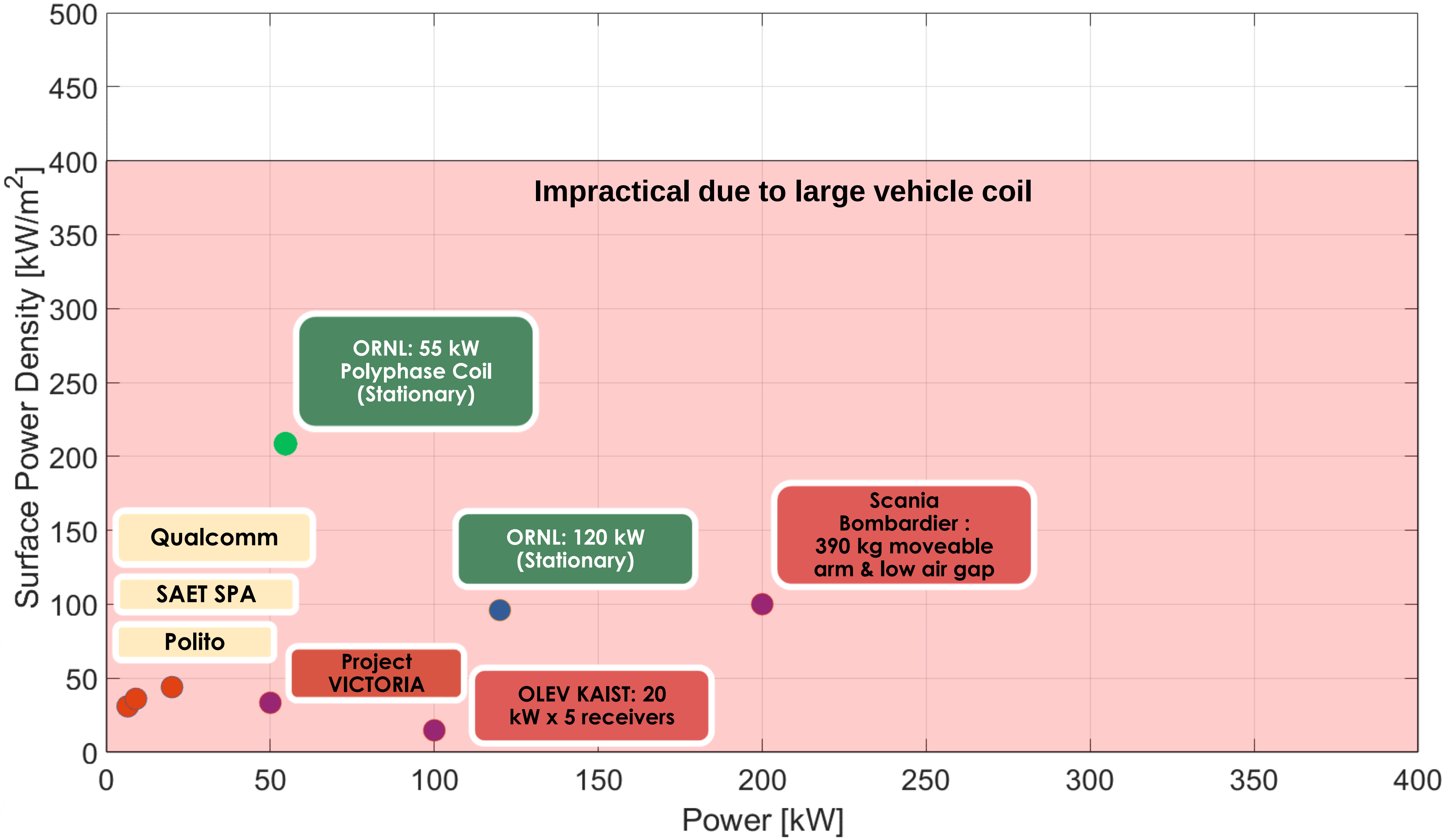
Buses
(Impractical for LD vehicles)

Stationary
(Impractical for DWPT)

SOA systems are not practicable for LD vehicles: Low surface power density

Target for feasibility (LD):

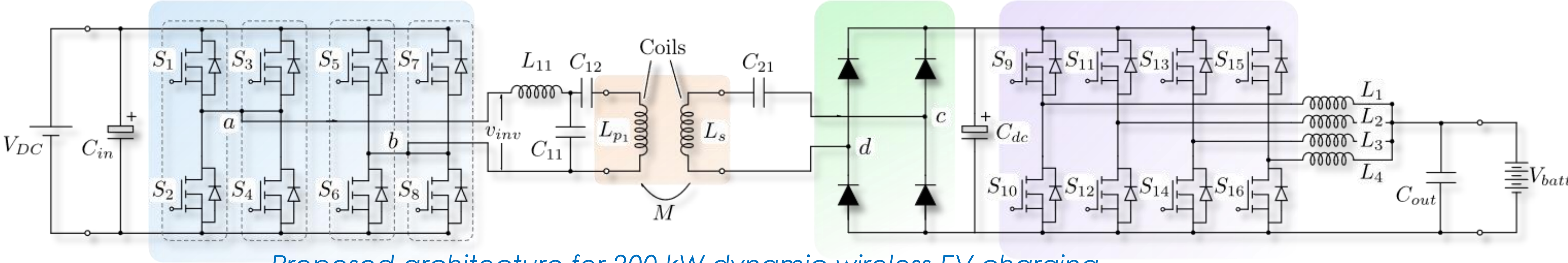
- Power = 200 kW (150 – 235 kW)
- SPD ~ 400 kW/m²



Power transfer level and surface power density of state-of-the-art DWPT demonstrations

Technical Accomplishments FY20: Identified Architecture Suitable for 200 kW DWPT

Goal: To identify an architecture which optimizes performance (efficiency, weight, and volume) without compromising safety and controllability.
Challenge: High power transfer rate in short time span exasperates control challenges



Proposed architecture for 200 kW dynamic wireless EV charging

Primary Side HF inverter
- Input: 680 V – 800 V DC
- Peak power: 200 kW
- Frequency: 85 kHz
- Phase-leg modules per phase: 2
- Optimized 85 kHz operation

Primary Side LCC tuning
- Load independent coil current
- Soft switching over wide operating range
- Eliminates requirement of transformer

Secondary Side Series Tuning
- Reduced weight and volume
- Eliminate issue of over-voltage on secondary side

DD Coil architecture
- Reduced power oscillations
- Reduced emissions compared to circular

Secondary Side HF Rectifier
- Optimized for 85 kHz operation

Secondary Side DC-DC converter
- Input voltage < 800 V
- Output: 400 V system
- Four phases (Optimal)
  - Reduced input and filter capacitor
  - Smaller inductor
  - Faster dynamic response
  - Improved light load efficiency

Technical Accomplishments FY20: Completed Primary Power Electronics Component Selection

Goal: To select components which will enable a power dense high performance 200 kW inverter
Challenge: High frequency and high current operation require optimized layout and components with minimal parasitic inductances

Identified components for 200+ kW inverter operating at 85 kHz

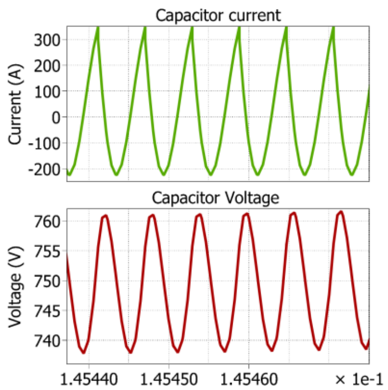
- Estimated worst case losses at 85 kHz: single module option is thermally in-feasible
- Simulated current harmonics in decoupling capacitor: current sourcing capability up to 1 MHz is required
- Components with low parasitic inductance are required
  - Low ESL (4 nH) CeraLink capacitor
  - Low ESL (5 nH)1200 V 325 A Wolfspeed SiC module

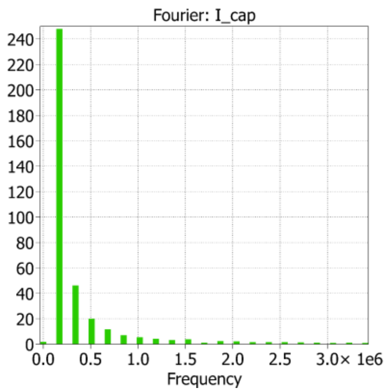
CAS325M12HM2
1200 V, 325 A SiC Module

B58033I9505M001
5 µF,1300 V Capacitor

Summary of evaluation of power semiconductor modules for 200+ kW 85 kHz operation

	CAB450M12XM3		CAB400M12XM3		CAS325M12HM2	
Modules in parallel	1	2	1	2	1	2
Total Loss (kW)	4.144	3.879	2.571	2.025	2.299	**1.821**
Inverter Efficiency	0.983	0.984	0.989	0.991	0.990	**0.992**





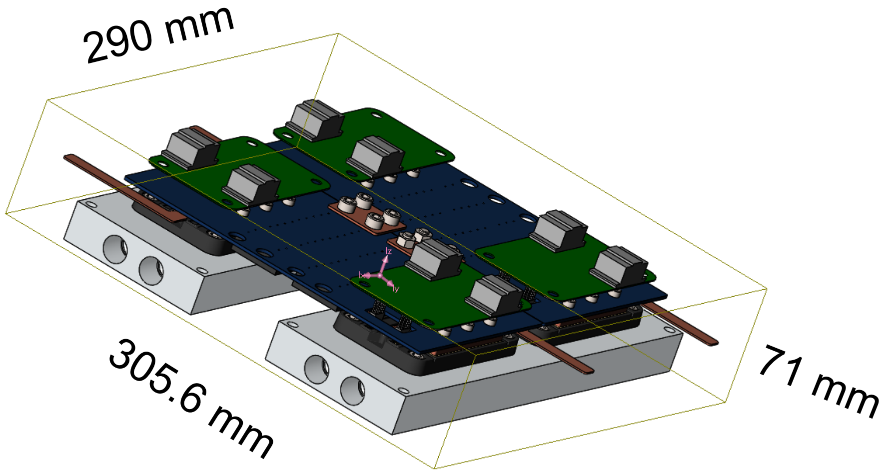
Freq	**170kHz**	**340 kHz**	**510 kHz**	**680 kHz**	**850 kHz**	**1.02 MHz**
Current (A)	248	46	20	11.5	7	5.5

Simulated capacitor current, voltage, and capacitor current harmonics for 250 kW operation

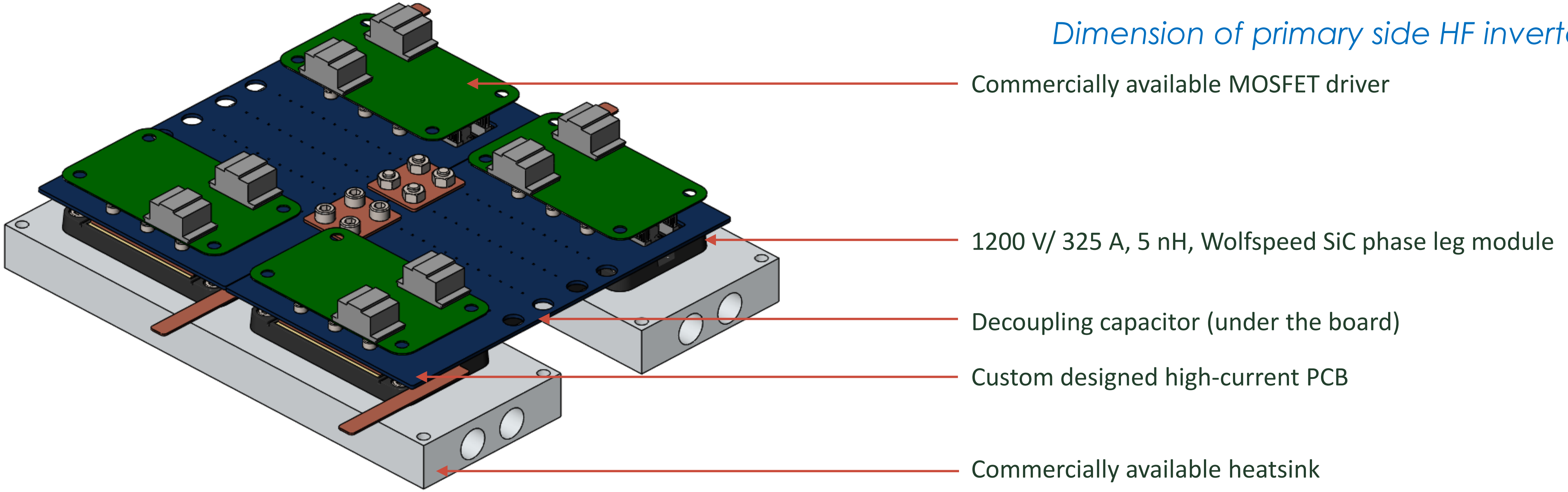
Technical Accomplishments FY20: Completed Primary Side Power Electronics Design

Optimized primary side inverter design

- 200+ kW operation at 85 kHz
- 305.6 mm x 290 mm x 71 mm
- 6.29 L → Power density ~ 31.78 kW/L
- Estimated efficiency ~ 99 %
- Custom designed and optimized PCB (bus-bar)



Dimension of primary side HF inverter



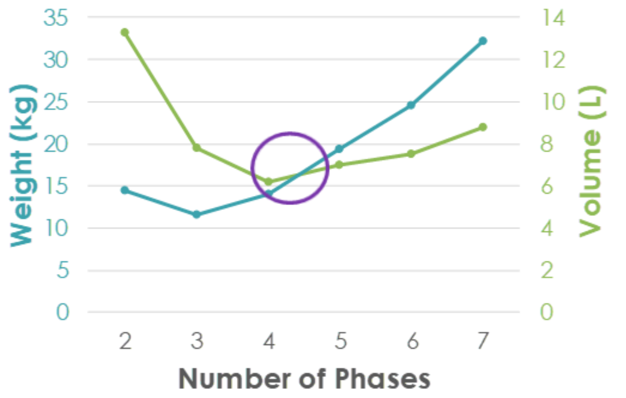
Optimized 200 kW primary side inverter

Technical Accomplishments FY20: Completed Secondary Side Power Electronics Component Selection

Goal: Minimize the weight and volume of onboard component of the 200 kW dynamic charging system
Challenge: Minimizing weight and volume exasperates the challenge of thermal management

Completed component selection of DC-DC converter and HF rectifier

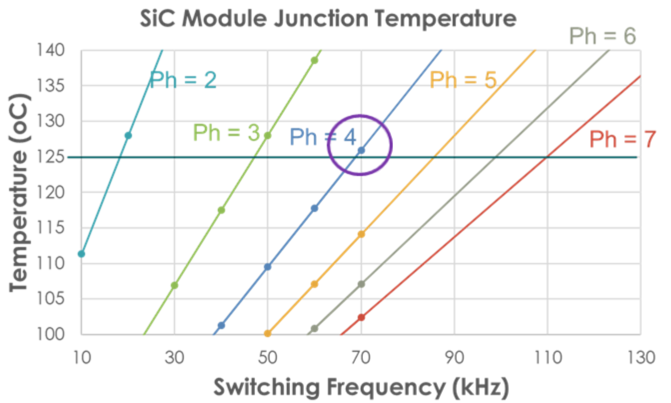
- Identified optimal number of phases (4) and frequency (70 kHz)
- SiC module selected for primary inverter is optimal for secondary rectifier and DC-DC converter



Weight and volume of the DC-DC converter as a function of number of phases

Evaluation of modules for secondary side HF rectifier

	GB2X100MPS12-227 SiC Schottky Tj at 125°C	APTDF400U120G Si p-n junction Tj at 100°C	CAS325M12HM2 MOSFET Tj at 125°C
Quantity	8	4	4
Total size (sq.in)	12.89	31.64	44.33
Losses (W) @ 240 kW output	1792	1512	1350



Junction temperature as a function of frequency and phases of DC-DC converter

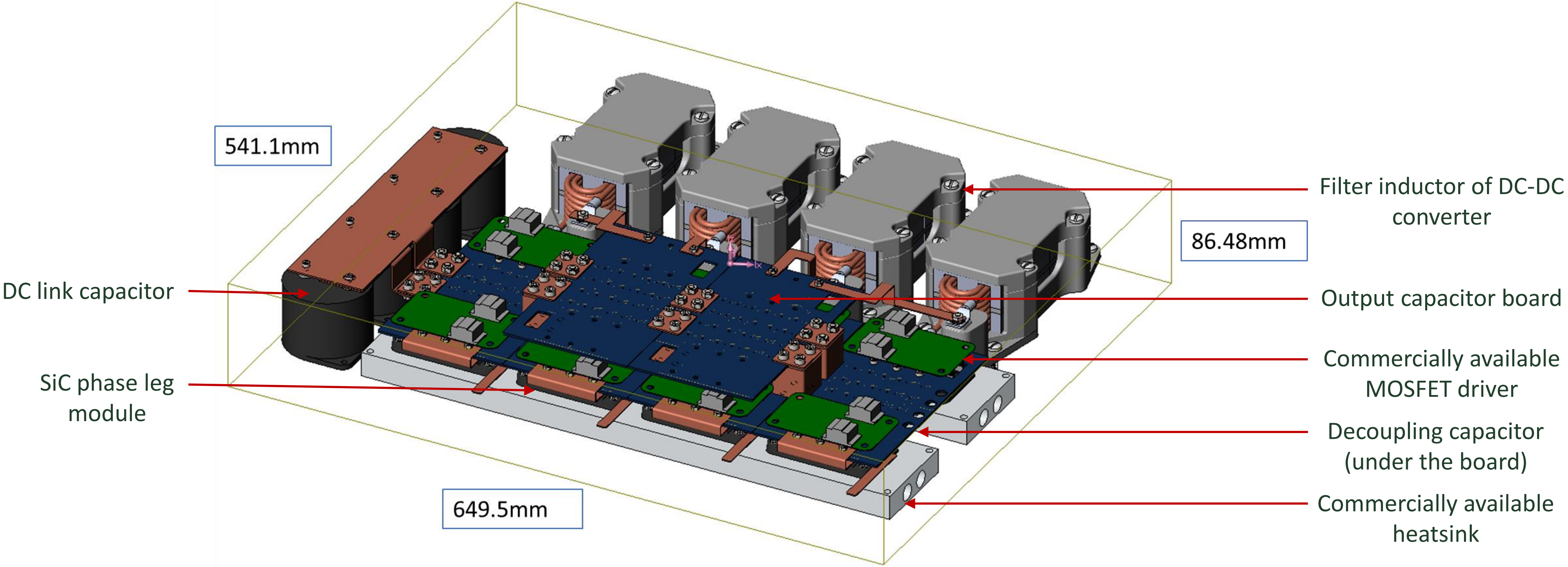
Technical Accomplishments FY20: Completed Secondary Side Power Electronics Design

Optimized secondary side power electronics

- Integrated package for 200+ kW rectifier and DC-DC converter
- Optimized high frequency (70 kHz) 4 phase buck DC-Dc converter
- Nano-crystalline based power dense magnetics
- 649.5 mm x 541 mm x 86.48 mm

4 phase Buck DC-DC converter

- Optimized overall mass and volume
- Improved light load efficiency by load shedding
- 4 times smaller filter capacitor and inductors
- Improved dynamic response



Optimized secondary side HF rectifier and DC-DC converter

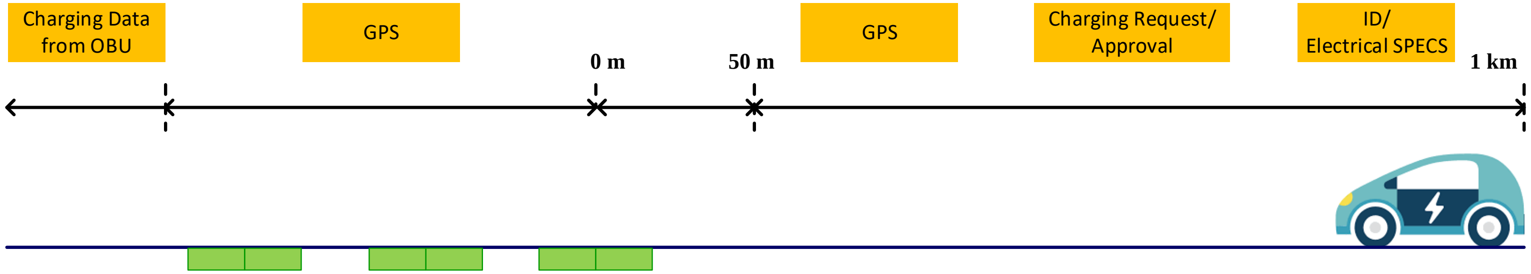
Technical Accomplishments FY20: Identified Control Architecture to Minimize Impact on EV Battery and Utility

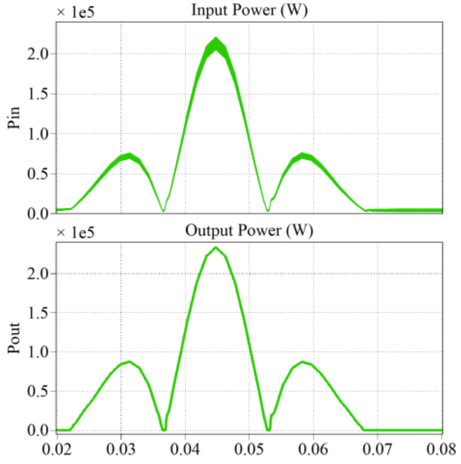
Goal: Provide accurate and wide range EV charging voltage and current control with minimal impact to utility

Issue: High power DWPT leads to pulse-like load profile, which can affect the utility grid stability and EV battery charging process

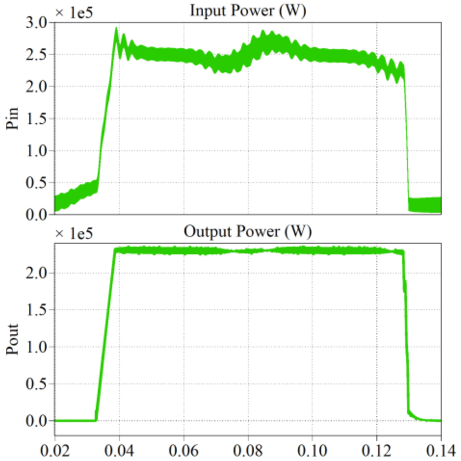
Control System Architecture

- Central controller: Charging sequence management
- Primary and on-board controller: Accurate and fast control loop
- Communication range and latency consideration

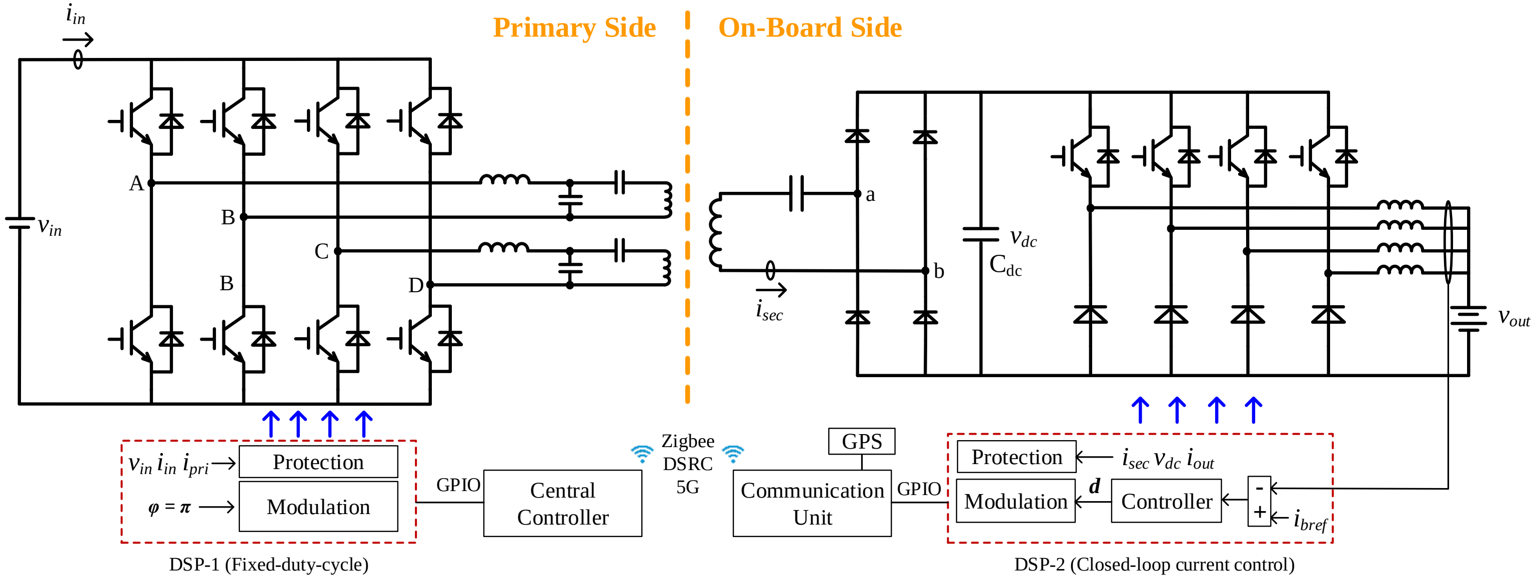




Conventional Architecture



Proposed Architecture



Proposed optimized dual side control architecture with primary side LCC and secondary side series tuning

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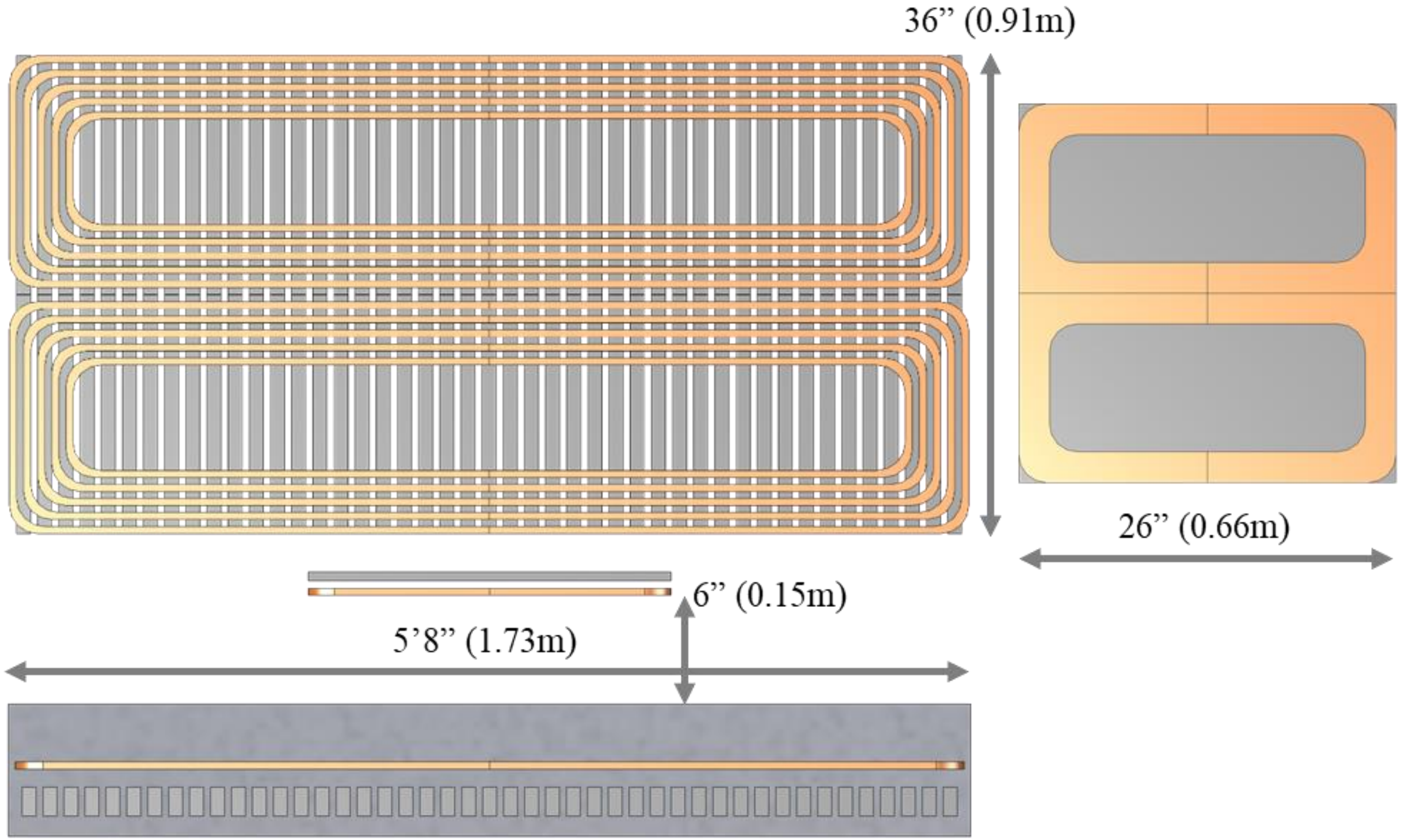
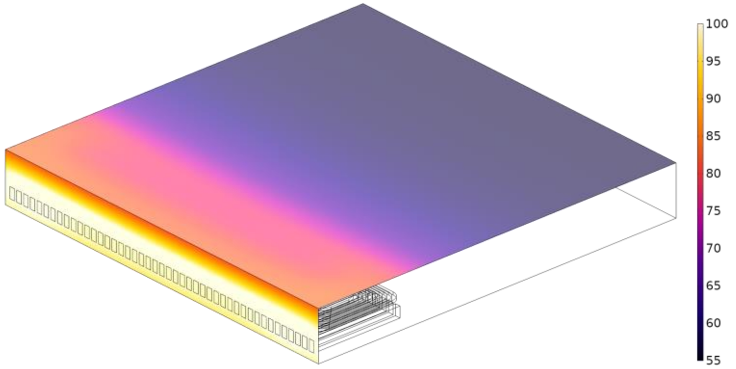
Technical Accomplishments FY20: Completed Design of DWPT with Practical Constraints

Goal: Ensure feasibility of construction and operation of roadway embedded DWPT system

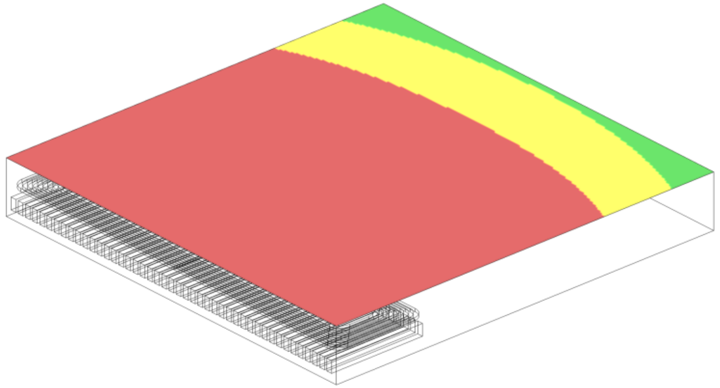
Challenge: Thermal, mechanical, and field emissions constraints limit the ability of embedded transmitters to push power across a large magnetic airgap



Views of the ground coupler (top left) and vehicle coupler (top right); Side view of the ground coupler showing the surrounding concrete and vehicle coupler ground clearance



Thermal analysis of DWPT system embedded in concrete with ambient temperature of 55C

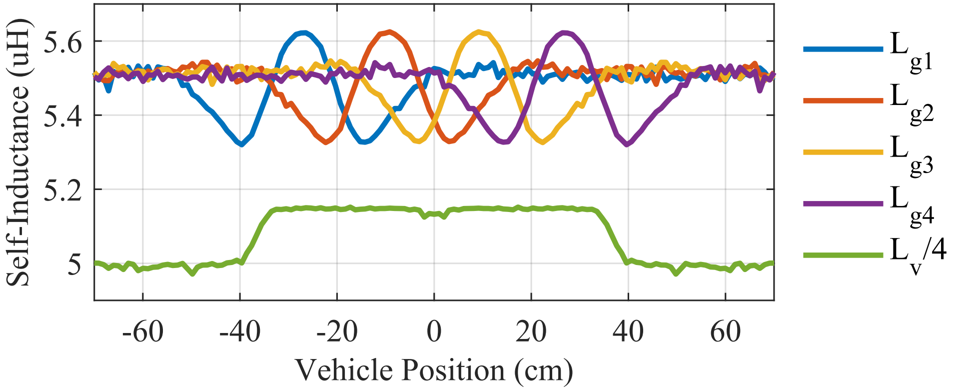


Electromagnetic field emission on the roadway; Green less than 15 μT rms, Yellow – between 15 μT rms and 27 μT rms; Red greater than 27 μT rms

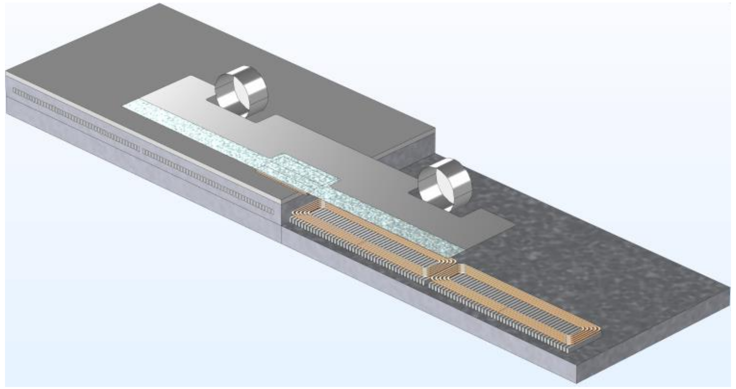
Technical Accomplishments FY20: Analyzed Vehicle Position Dependent System Parameters

Goal: Develop accuracy DWPT system models

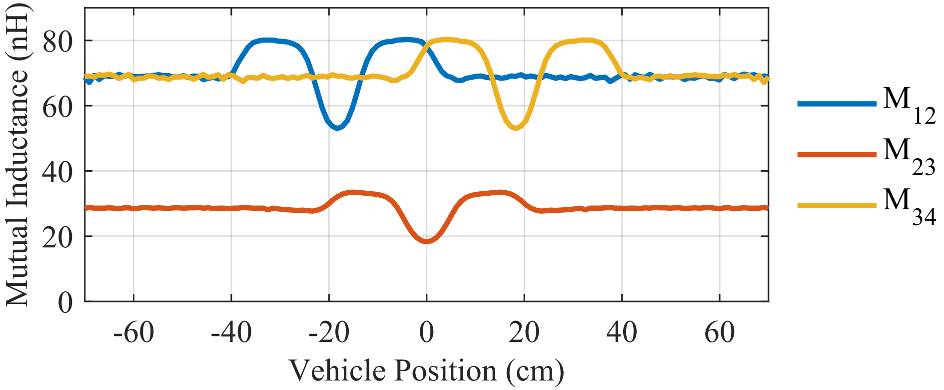
Challenge: Self-inductances, mutual inductances, and parasitic resistances depend on vehicle position



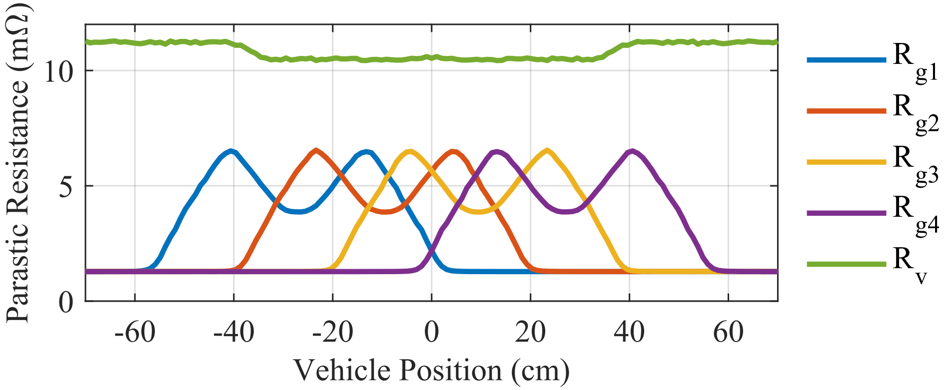
Transmitter self-inductance depends on vehicle position



FEA model used to investigate transmitter coupling, vehicle position dependent system parameters, and vehicle body losses



Mutual coupling between the transmitters also depends on vehicle position

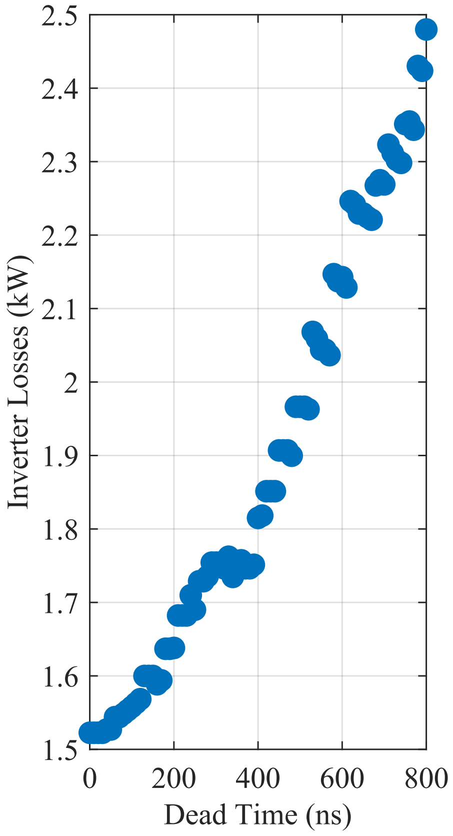


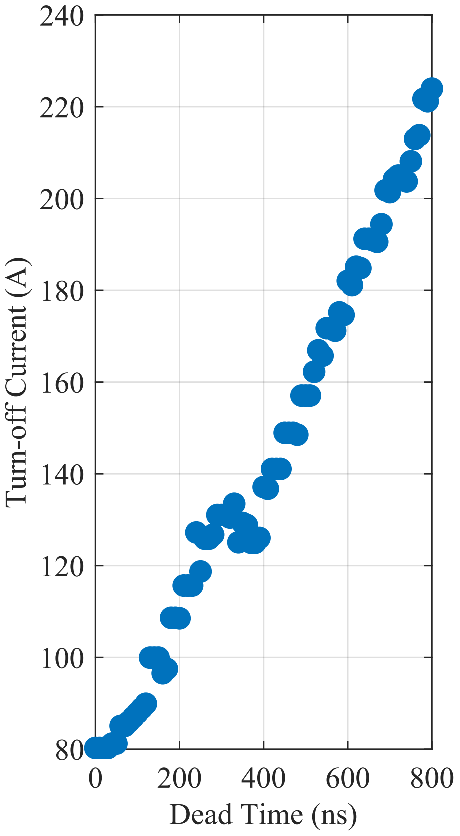
Equivalent series resistance of the transmitters change because 1) dependency of chassis losses on vehicle position 2) core loss variations due to changes in self- and mutual inductances

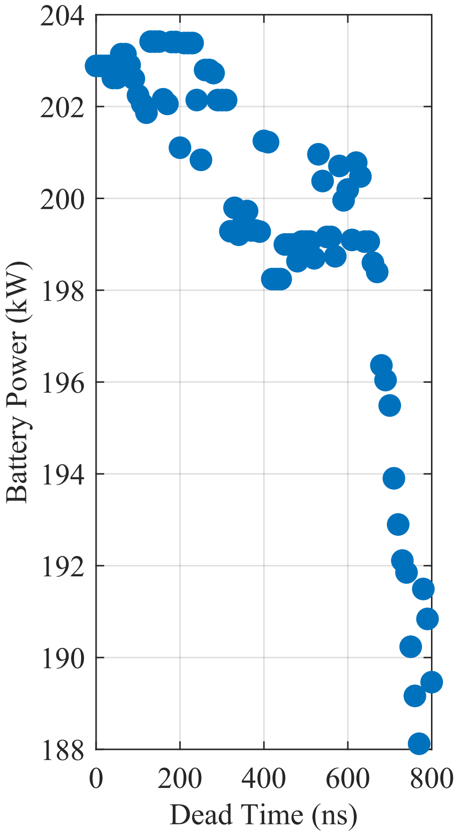
Technical Accomplishments FY20: Performed Tuning Design to Ensure Wide Range Zero-Voltage Switching

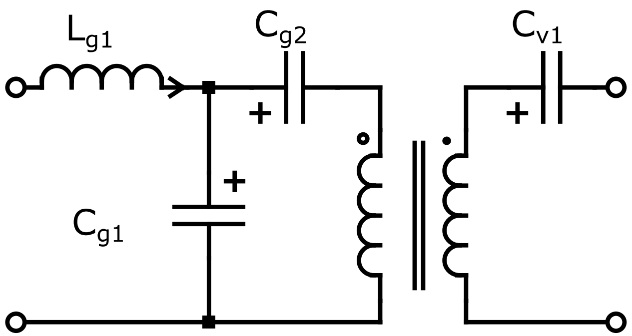
Goal: Ensure reliable operation of the inverter

Challenge: Dead-time movement of the vehicle need to be considered to minimize inverter losses and maximize power transfer capability when designing the compensating network









Dead Time	0ns	600ns
L_{g1}	1.992μH	2.356μH
C_{g1}	2.004μF	2.146μF
C_{g2}	1.034μF	0.917μF
C_{v1}	174.5nF	177.9nF

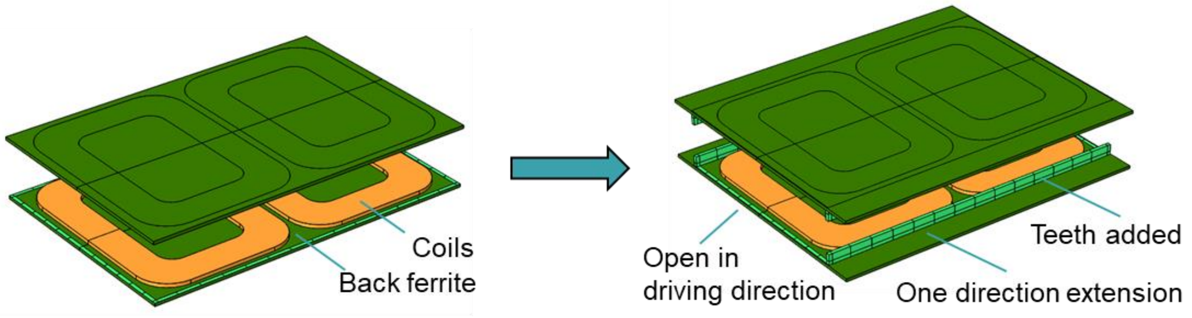
Comparison of tuning parameters for wide load-range, vehicle position independent ZVS for the ideal case (0ns dead-time) and 600ns dead-time

Steady-state average DWPT inverter characteristics as a function of dead-time for tunings which achieve wide load-range ZVS at a fixed frequency: (Left) Inverter turn-off current, (Middle) inverter Losses, (Right) average power transfer

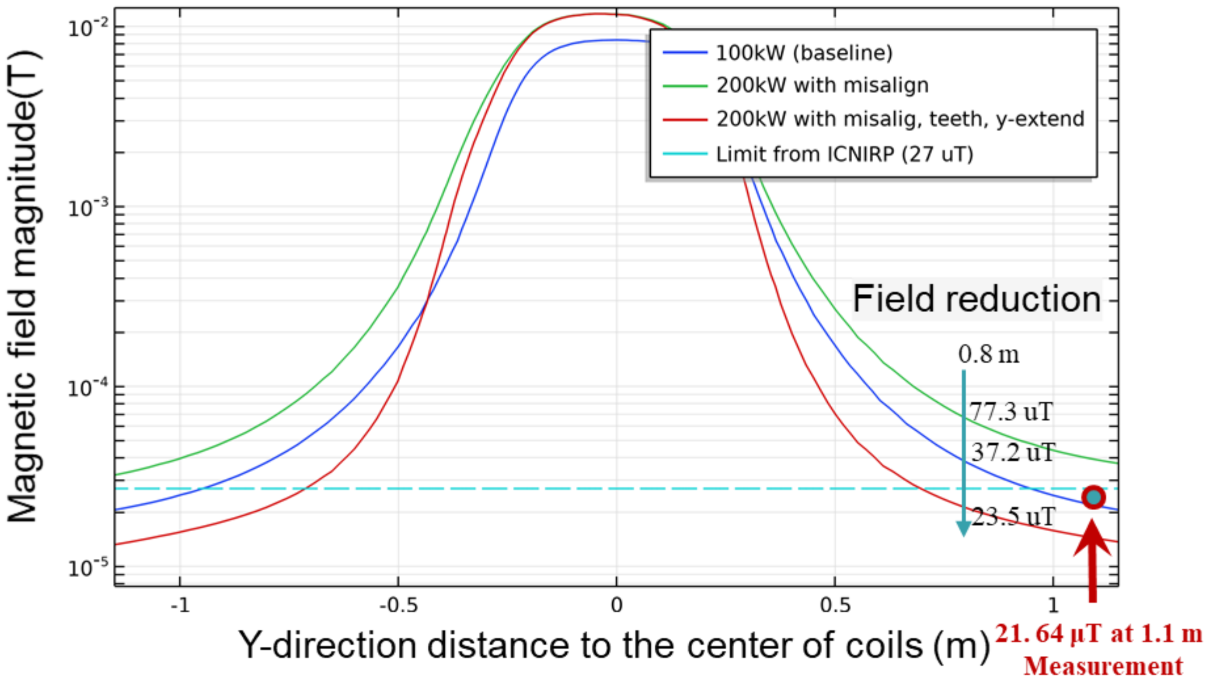
Technical Accomplishments FY20: Passive EM-field Shielding Design for 200kW DWPT system

Goal: Safe EM-field operation of DWPT at 200kW
Issue: High power transfer for light duty EVs, requires high magnetic flux density. Proper EM-field shielding is required to ensure safe EM-field levels during WPT operation.

- Considerations: 200 kW WPT operation with misalignments
- Mitigation measures/passive ferrite shape designs
  - Add teeth to centralize EM fields
  - Extend backing ferrite(side to side direction) to be tolerant of misalignment
- Standards considered: SAE J2954 and ICNIRP 2010
- Passive shielding design is completed
- To be integrated with ORNL's 200 kW DWPT



New passive shielding design with teeth for dynamic WPT

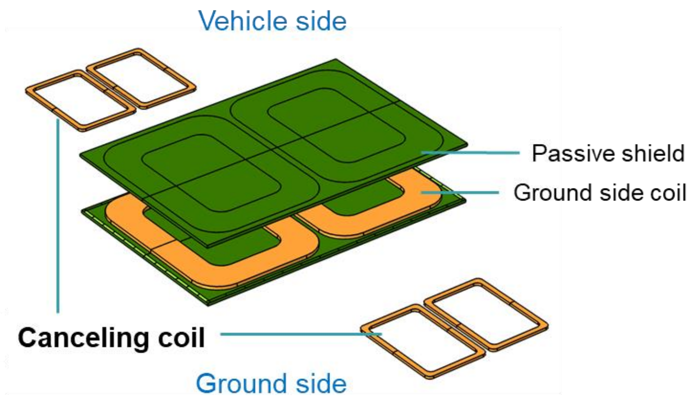


Simulated magnetic field for 200 kW coil with and without shielding in comparison with 100 kW baseline and ICNIRP limit

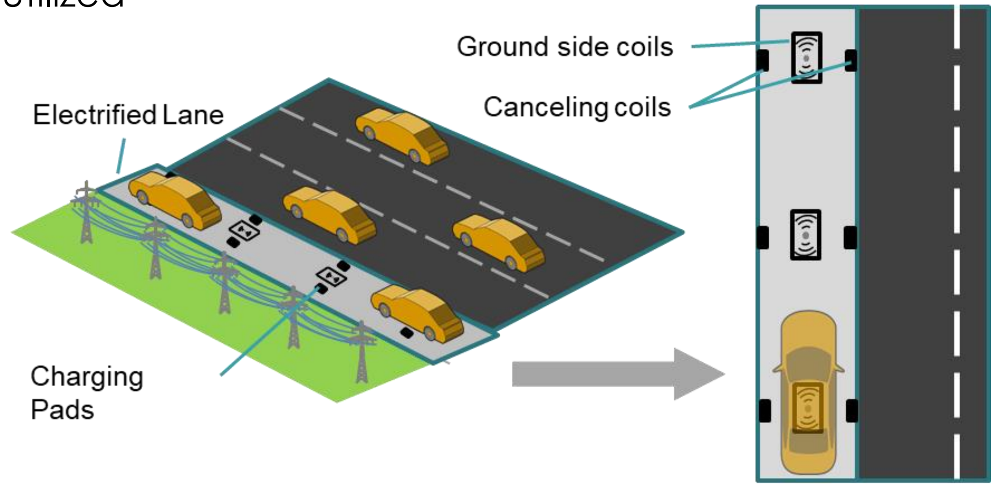
Technical Accomplishments FY20: Active EM-field Shielding Research for High Power DWPT

Goal: Research alternative solutions to passive EM-field shielding for high power DWPT
Issue: Ferrite used with passive shielding is brittle and expensive

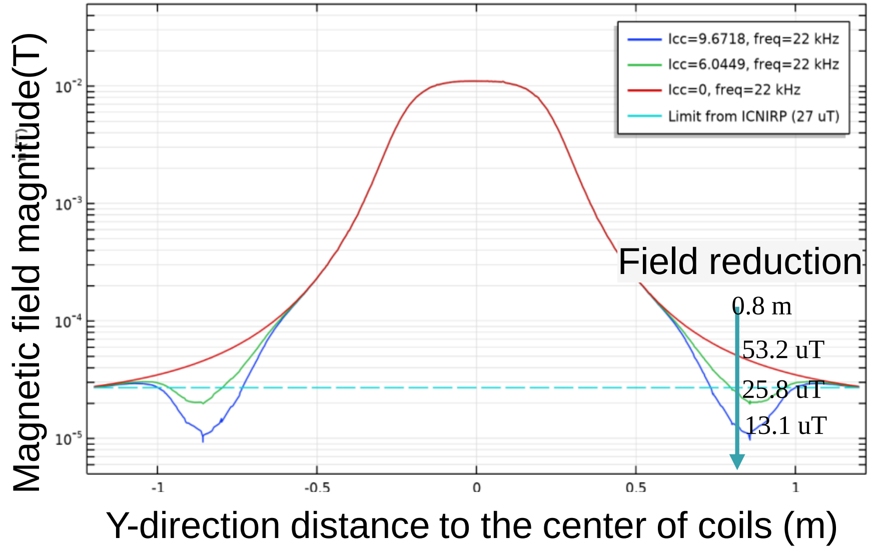
- Active shielding is a good supplemental solution to passive shielding for dynamic WPT due to the benefits in
  - Flexible shielding effectiveness
  - Reasonable cost when installed along road
- Technical features
  - No coupling between canceling coils and main coils
  - Efficiency reduction<1% when low canceling currents are utilized



Proposed active shielding concept



Depiction of active shielding coils embedded in real-world DWPT system

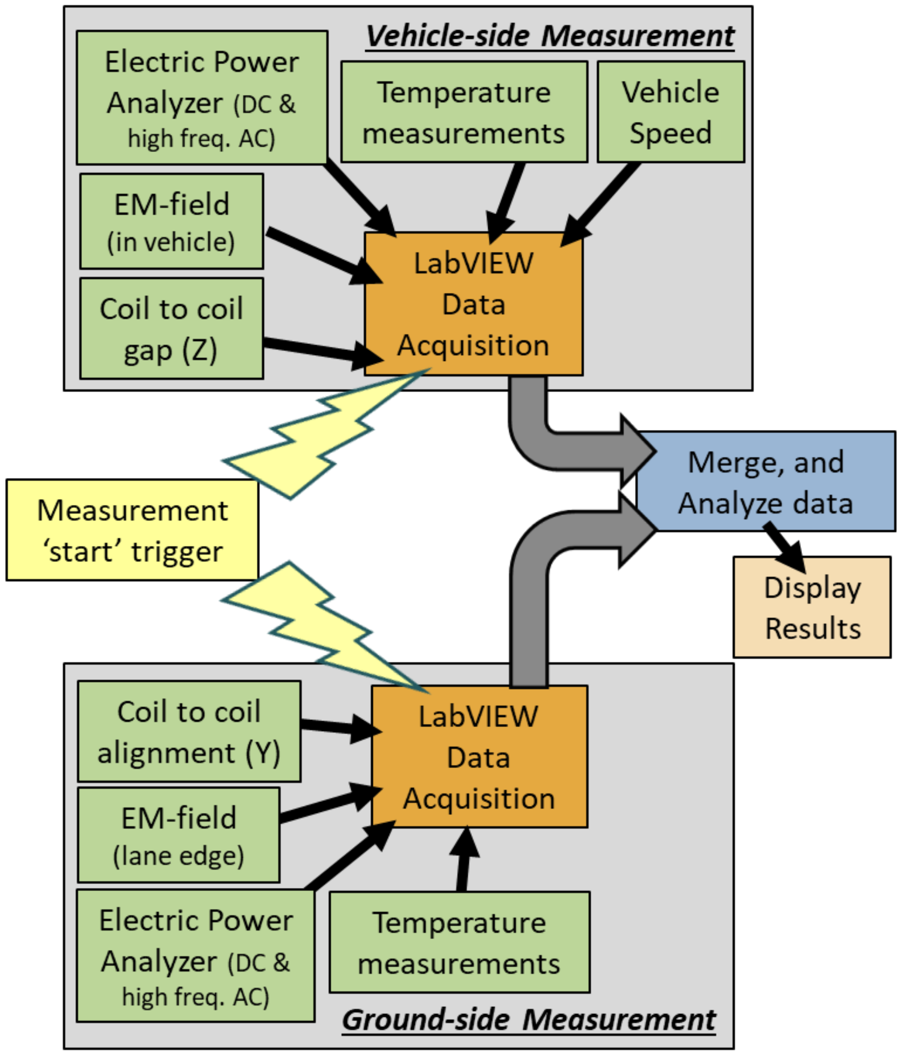


Simulated magnetic field for 200 kW coil with active shielding coil with 9.6 A (4 % of primary coil current), 6 A (2.5 % of primary coil current) and no cancelling coil current

Technical Accomplishments FY20: Data Acquisition System Design and Requirements

Goal: Develop data acquisition system for DWPT system
Issue: Synchronous data must be collected from multiple location, during high speed DWPT operation

- DWPT measurements
  - Power transfer: DC, high freq. AC
  - Efficiency: DC to DC, sub-system, etc.
  - EM-field emissions: at roadway lane edge, in vehicle
  - Operating conditions: vehicle speed, coil alignment, coil gap
  - Component temperatures: coils, inverter, rectifier, etc.
- Synchronized measurement from multiple sources
  - On vehicle components
  - From ground-side components
  - Operating conditions
- Data analysis and postprocessing
  - Enables faster development and system refinement
- Completed data acquisition system design is completed



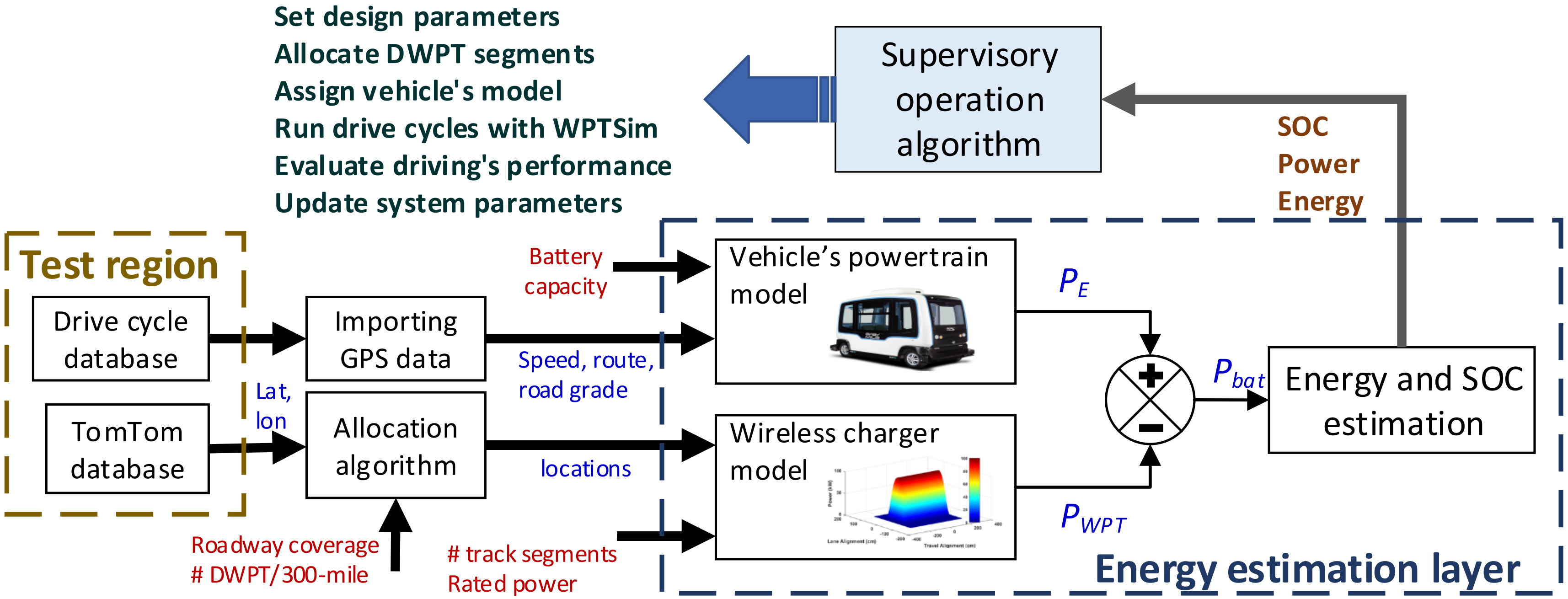
Data acquisition system developed for real-world 200 kW DWPT system

Technical Accomplishments FY20: Developed E-Roads Tool for Analyzing Large-Scale Deployment of DWPT

Goal: Development of a new tool (E-Roads) that provide testing capability for large-scale deployment of DWPT system

E-Roads includes:

- Link with real-world GPS vehicle travel database,
- Link with real roadway network database,
- Automatic allocation tool for DWPT segment on roadways, and
- Supervisory algorithm (Import drive cycles, estimates vehicle's energy, analyzes output, and updates inputs).



Operational representation of E-Roads tool for analysis of large-scale deployment of DWPT systems

Technical Accomplishments FY20: Analyzed Feasibility of Large-Scale Deployment of DWPT system on Primary Roadways in Atlanta

NREL Transforming ENERGY

Goal: Exploring feasibility of implementing DWPT system in Atlanta and its impact on the vehicle's driving range

Test Data:

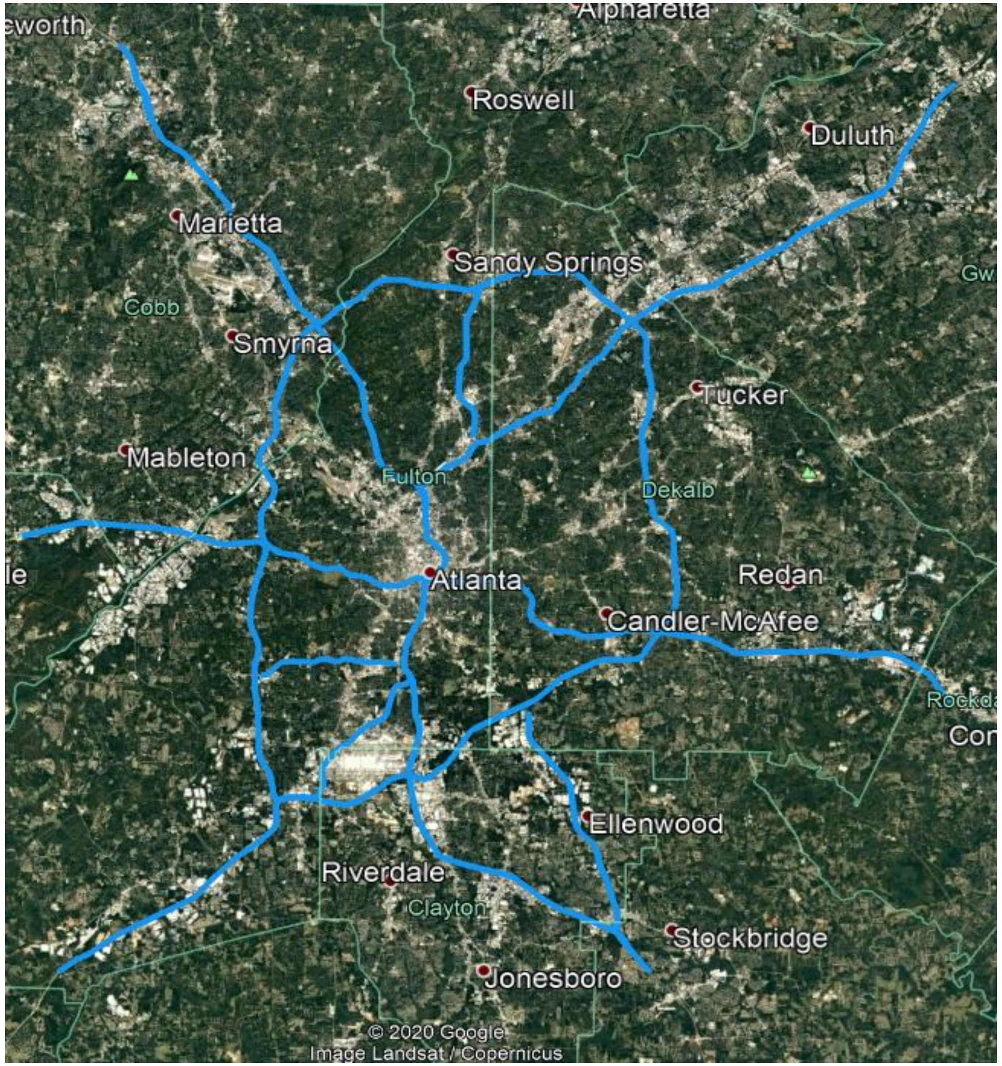
- Real world, 1 Hz driving data collected from 1652 vehicles in Atlanta metro area.
- Represents ~120,000+ miles traveled and ~4,200 24-hour tours
- 427 paved miles (213 miles in each direction) of primary roadways around Atlanta are considered for electrification.

Test Cases (12 cases):

- Three DWPT system designs are considered based on FY19 work.
- Four different uniformly distributed allocations are tested.

Results of three DWPT systems as applied to Atlanta

	DWPT1	DWPT2	DWPT3
Battery size (kWh)	59	30	30
Efficiency (Wh/mile)	280	270	270
Charging power (kW)	235	225	200
Road coverage (%)	8.2	16.6	14.56
#DWPT/300-mile	40, 60, 80, 100	40, 60, 80, 100	40, 60, 80, 100
Elec. Segment (mile)	0.62, 0.41, 0.31, 0.25	1.25, 0.83, 0.62, 0.5	1.09, 0.73, 0.55, 0.44
Non-elec. Segment (mile)	6.88, 4.59, 3.44, 2.75	6.25, 4.17, 3.13, 2.5	6.41, 4.27, 3.2, 2.56



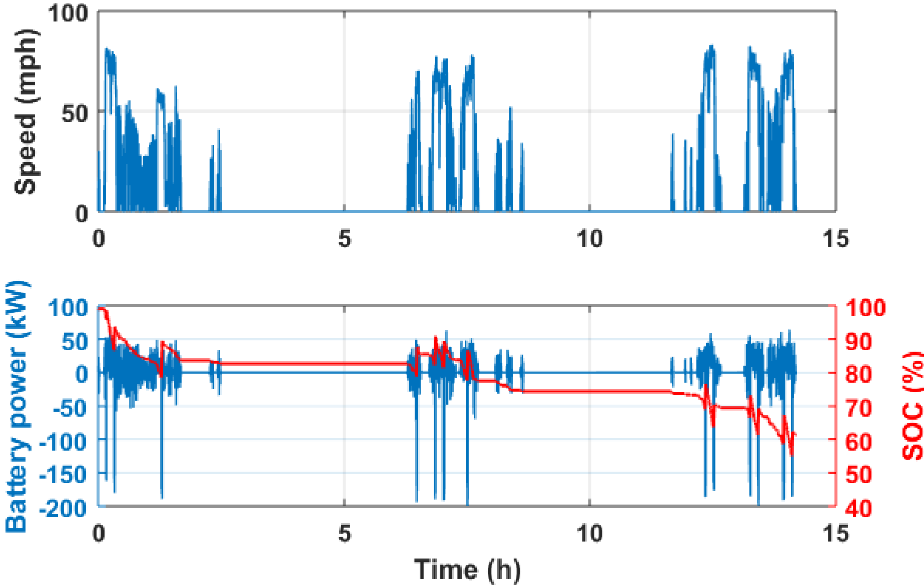
Primary roadway network considered for electrification

Technical Accomplishments FY20: Analyzed Feasibility of Deployment of DWPT System on Primary Roadways in Atlanta

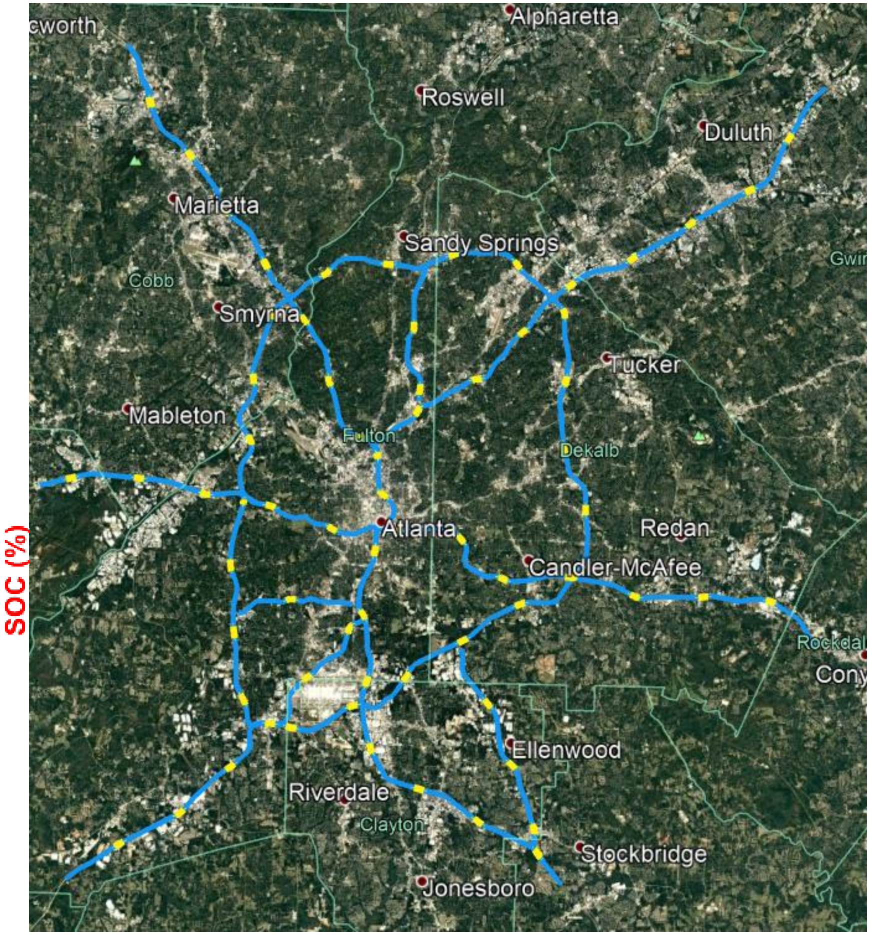
Goal: Exploring feasibility of implementing DWPT system in Atlanta and its impact on the vehicle's driving range

- Evaluated ~120 24-hour tours (~3,600 miles travel) with 12 different DWPT system designs.
- Charge sustaining (CS): ΔSOC≤40%.
- Range extension (RE): 40%<ΔSOC<80%.
- Charge depletion (CD): ΔSOC≥80%.
- Insufficient Range(IR): SOC≤0%.
- **0% of tours show more than 40% ΔSOC (CD & IR).**
- Increasing the number of locations is not always better.
- 60 locations/300-mile shows reasonable results with all designs.
- DWPT1 shows 100% CS for nearly all cases simulated

A single 24-h tour for running for DWPT3 system with 40 DWPT/300mile



#DWPT/300mile	DWPT1	DWPT2	DWPT3
40	CS:99.17%; RE:00.83%	CS:96.72%; RE:03.28%	CS:95.08%; RE:04.92%
60	CS:100.0%; RE:00.00%	CS:98.36%; RE:1.64%	CS:98.36%; RE:01.64%
80	CS:100.0%; RE:00.00%	CS:99.17%; RE:08.33%	CS:98.32%; RE:01.68%
100	CS:100.0%; RE:00.00%	CS:98.36%; RE:01.64%	CS:97.54%; RE:02.46%



DWPT system locations on primary roadways in Atlanta considering 14.56% coverage and 100 segment/300- mile

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Response to Previous Year Reviewers' Comments

Reviewer Comment: The reviewer suggested that there could be more details as to how the barriers can be overcome instead of terming it broadly under "novel" solutions or technologies.

Reply: FY 19 was the first project year and the required solutions were in the nascent phase. They have been highlighted in the FY 20 presentation namely:

- Novel resonant tuning methodology (including effect of non-idealities)
- Optimal power electronics design to enable 85 kHz operation at 200 kW
- Active and passive shielding techniques
- Novel control-hardware-in-the-loop and power-hardware-in-the-loop techniques to develop optimal control strategy.

Reviewer Comment: The reviewer suggested that even with dynamic charging enabled vehicle, if the driver wants to drive on a tertiary road without dynamic charging, he/she must be able to do it without being restricted to electrified roadways only.

Reply: We completely agree with the suggestion, and in the feasibility study analyses we have stipulated a minimum battery capacity of 37 kWh which can provide over 100 miles range for LD vehicles.

Reviewer Comment: The reviewer suggested that the proposed solutions are not mature and as an example pointed out that it was not clear how time domain simulation models will be used for developing controllers.

Reply: We are developing time domain simulation models and implementing in real time simulation platform (OPAL-RT) to interact with the control board as a preliminary step. This will be followed by replacing the real-time simulator with actual dynamic charging system in the laboratory. The final step will be evaluation of vehicle integrated charging system.

Collaboration and Coordination with Other Institutions

Laboratory partners:

Oak Ridge National Laboratory	• Project lead • 200 kW power dynamic EV charging system design, simulation, hardware development, vehicle integration and validation
INL Idaho National Laboratory	• Design of active and passive shielding and data acquisition system for 200 kW dynamic EV charging system
NREL Transforming ENERGY	• High level cost study of high power dynamic wireless EV charging • Study of large scale deployment scenarios of high power dynamic EV charging

Coordination with Other Institutions:

HYUNDAI MOTOR GROUP	• Kona EV for high power dynamic wireless EV charging demonstration • Engineering support and guidance for integration of DWPT system with the vehicle
American Center for Mobility CONNECTED. AUTOMATED. VALIDATED.	• Site for 'electrified mile' dynamic charging demonstration (FY21) • Infrastructure and support for demonstration
VIRGINIA TECH TRANSPORTATION INSTITUTE	• Evaluation and guidance of making the ground side coils and power electronics roadworthy

Remaining Challenges and Barriers

- **ORNL**
  - Evaluate and overcome the effect of vehicle body interference on power transfer efficiency
  - Implementing accurate and fast control over wide range of power level (0 – 200 kW)
- **NREL**
  - Finding a test region with enough real-world drive cycle data available
  - Developing a tool that matches real-world drive cycle data with real roadway network
  - Analyzing dynamic design variables using large data set with 1 Hz resolution
- **INL**
  - DWPT EM-field measurement reference distance (from coil center)
    - 0.8m is standardized measurement distance for static WPT (i.e. edge of vehicle), but for DWPT, the roadway lane edge is likely more appropriate
    - Wide range of lane widths worldwide (2.5m to 3.7m wide) dependent upon roadway use and speed rating
  - Advanced EM-field shaping design and optimization
    - High cost of passive ferrite shielding vs. increased complexity of active shielding
    - Advanced EM shaping designs/ structures to elongate equivalent power transfer distance & save infrastructure costs

Any proposed future work is subject to change based on funding levels

Proposed Future Research

Research:

- Explore the possibility of replacing secondary passive rectifier and DC-DC converter with a single active rectifier
- Explore power electronics and control techniques to minimize the number of ground side power electronics unites required.

Tasks/Milestones:

- **FY 2020**
    - Validate 200 kW WPT power transfer capability
    - Integrate INL's passive EM-field shielding solution with ORNL's 200kW DWPT system
    - Complete analysis and results for DWPT system in Atlanta considering different designs, allocations, and EV models.
- **FY 2021**
    - Complete vehicle integration and validation of 200 kW dynamic wireless EV charging system
    - Validate and explore if necessary alternative EM-field shielding solutions for safe high power DWPT operation
    - Analyzing travel itinerary database developed for RECHARGE / DIRECT-XFC project(s) for larger data set, also including MD/HD vehicles

Any proposed future work is subject to change based on funding levels

Summary

- **Relevance**: Dynamic EV charging can significantly alleviate range anxiety and concurrently reduce the on-board battery requirement (weight and cost reduction)
- **Approach**:
  - Optimal range of power transfer level for feasible dynamic wireless EV charging system has been identified (150 kW – 235 kW)
  - Key R & D necessary to realize a practicable 200 kW dynamic charging system have been identified and being pursued for hardware development
  - 200 kW DWPT power transfer capability will be validated in a laboratory dynamic emulator before being implemented on a vehicle platform for final demonstration
- **Technical Accomplishments:**
  - Completed high-Level cost and feasibility studies and identified architecture suitable for 200 kW DWPT
  - Completed primary and secondary side power electronics design of 200 kW DWPT system
  - Identified power electronics and control architecture to minimize Impact on EV battery and utility
  - Completed design of DWPT coils and tuning network including the effect of parasitics, non-idealities, and vehicle dependent parameters
  - Identified and developing active and passive EM-field shielding solutions for 200kW DWPT system
  - Developing data acquisition system necessary for real-world implementation of 200 kW DWPT system
  - Analyzed Feasibility of Large-Scale Deployment of DWPT system on Primary Roadways in Atlanta
  - Developed E-Roads Tool for Analyzing Large-Scale Deployment of DWPT system on Roadways in a Region
- **Collaborations and Coordination with Other Institutions**:
  - HATCI providing an EV and support and guidance on vehicle-integration of DWPT system
  - ACM providing infrastructure and physical proving grounds for validation of 200 kW DWPT system
  - VTTI providing guidance and support to develop roadworthy DWPT coils
- **Future Work**:
  - Validate functionality of 200 kW DWPT system in laboratory
  - Demonstrate practicability by means of vehicle integrated demonstration at ACM

Any proposed future work is subject to change based on funding levels